DOCUMENT RESUME

ED 245 189 CS 007 623

AUTHOR Bulcock, Jeffrey W.
TITLE The Interaction of Basic Skills and Reading Comprehension.
SPONS AGENCY Social Sciences and Humanities Research Council of Canada, Ottawa (Ontario).
PUB DATE Apr 84
NOTE 50p.; Paper presented at the Annual Meeting of the International Reading Association (29th, Atlanta, GA, May 6-10, 1984).
PUB TYPE Reports - Research/Technical (143) -- Reports - Descriptive (141) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Achievement Gains; *Achievement Rating; Basic Skills; *Cognitive Processes; *Educational Research; Grade 4; Grade 6; Intermediate Grades; Language Processing; Language Skills; *Literacy; Mathematics Achievement; *Models; Reading Achievement

ABSTRACT

A series of six models were devised and tested to address the structure of elementary school achievement in language, work study, reading, and mathematics skills. The models were based on two assumptions: first, that information processing strategies of children would govern their basic skills performances; and, second, that the basic skills would be interrelated or mutually reinforcing. The six models include a revised model of discourse processing; recursive and nonrecursive models of the responsiveness of children's basic skills in grade four to their information processing strategies; a nonrecursive model of grade four literacy and numeracy; and longitudinal recursive and nonrecursive models of grade six literacy and numeracy. Results showed convincing support for the first model. Support for the second model, however, was not forthcoming. When literacy and numeracy in grade four were taken into account, the responsiveness of grade six reading to grade six mathematics was negligible; and the responsiveness of grade six mathematics to grade six reading was negative. Appendixes include a description of the variables, a matrix of correlations, and conceptual diagrams and equations for each of the six models. (HOD)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

X This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

ED245189

THE INTERACTION OF BASIC SKILLS AND READING COMPREHENSION*

Jeffrey W. Bulcock
Memorial University of Newfoundland

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Jeffrey W. Bulcock

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

April 1984

*Paper presented at the Twenty-Ninth Annual Convention, International Reading Association, Atlanta, Georgia, May 6-10, 1984. The research reported in this paper was supported by research grants awarded by the Social Sciences and Humanities Research Council of Canada.

CS 007 623

THE INTERACTION OF BASIC SKILLS AND READING COMPREHENSION

Purposes, Assumptions and Research Questions

What is the structure of elementary school achievement? The question is addressed in this paper through the formulation and estimation of a series of six models. Four are concerned with children's basic skills performances in grade four. Two are longitudinal designs of the responsiveness of literacy and numeracy in grade six to children's information processing strategies and literacy-numeracy performances in grade four. A caveat is in order at the outset. These are tentative models in that the gap between what is desirable in terms of identifying the structure of elementary school achievement and what is accomplished in this study is still far too large. Nevertheless, the results of the inquiry are believed to be sufficiently interesting to the educational research community as to be worth reporting.

What are the essential elements in models of the structure of elementary school achievement? This is the most important question to be addressed. By elementary school achievement we are referring to four basic skills; namely, language, work study, reading and mathematics skills. Later in the paper reading is used as a proxy for literacy and mathematics is used as a proxy for numeracy. This, then, is

our first simplifying assumption; that school achievement can be captured by these four skills.

Three further simplifying assumptions were made. It was assumed, second, that underlying the basic skills there are several identifiable strategies of information processing. Since some strategies can be expected to be more effective than others, one task of the researchers was to try to distinguish the more effective strategies from the less effective. It was assumed, third, that because basic skills development takes place over the course of an elementary school career -- grades one through six -- the strategies of information processing could shift in their effectiveness. A strategy which might be particularly valuable at one point in time, once mastered could be taken for granted; hence, would probably decline in relevance. In other words, strategies might be hierarchical; in which case lower order strategies might give way to higher order strategies.

Who would deny that achievement in one skill might stimulate achievement in another? The fourth assumption, then, was that school achievement outcomes in the elementary grades might be mutually reinforcing. According to this assumption, how well a child reads, for example, will depend not only on how well the child uses information processing strategies (assumption two) but also on how well the child performs in the other basic skills. The same logic would apply to each skill.

Models based on these assumptions will have two sets of components. First, the information processing strategies of children will govern their basic skills performances. Second, the basic skills will be interrelated or mutually reinforcing. The models, therefore, call for multiple feedback linkages between the basic skills.

On the basis of these research purposes and simplifying assumptions four research questions were formulated as follows:

(1) What are the information processing strategies that children use to decode and encode information?

(2) How responsive are the basic skills, including reading, to changes in children's information processing strategies?

(3) To what extent does the responsiveness of the basic skills to children's information processing strategies change over time? and

(4) Are the basic skills mutually reinforcing, and if so, to what extent?

In the next section of the paper we discuss the theory underlying the specification of the models designed to address these questions. Each question, therefore, is addressed in turn.

Theory

The Information Processing Strategies

Information processing models include the "bottom up" model with its emphasis on the transformation of letters and words into a phonemic code (Gough 1972; Gough and Cosky 1977); the "top down" model with its emphasis on a reader's prior

semantic knowledge and syntactic mastery (Goodman 1967, 1976; Smith 1971, 1973, 1978); the interactive model in which both bottom-up and top-down processes operate in parallel (Rumelhart 1977; Lesgold and Perfetti 1981); and the discourse processing model with its emphasis on reading recalls and text summaries (Kintsch 1974, 1976; Kintsch and van Dijk 1978; Kintsch and Vipond 1979; Meyer 1975, 1977; and van Dijk 1977). Beebe (1980, 1981, 1984) has developed measurement models of these processes; in particular models of children's cueing strategies and discourse processing strategies. Beebe argues that discourse strategies are responsive to the cueing strategies and that both account for comprehension in reading. Here, we accept these arguments and the attendant research findings uncritically and unconditionally. We extend them, however, by adding a new variable to the set of information processing variables; namely, background knowledge.

The Responsiveness of the Basic Skills to Children's Information Processing Strategies

Beebe (1984) shows that reading comprehension is highly responsive to information processing strategies. Here, we merely extend the logic by adding three more basic skills to the model; namely, language, work study and mathematics. We argue that the information processing strategies - bottom-up, top-down and discourse processing - in conjunction with

background knowledge will enhance the decoding and encoding of any information. As we have noted elsewhere (Bulcock and Beebe 1981) the syntactic and semantic structure of mathematics is as precise as that of the common language though the symbols differ. In sum, therefore, it seems plausible that the additional basic skills will be responsive to the information processing strategies in much the same way as reading is.

In Chart 1 the specified relationships are depicted in a conceptual model of elementary school achievement. Note that the relationships may be either recursive (as in Chart 1A) or nonrecursive (as in Chart 1B) depending on whether the basic skills are examined one at a time or simultaneously.

Chart 1 about here

The Magnitude of the Information Processing Parameters Over Time

The research design involved the estimation of the effects of the information processing strategies on the basic skills at two points in time. According to orthodox developmental reading theory important shifts in reading emphasis occur between the early grades and the middle grades and between the middle grades and the later grades of elementary schooling. In the first place there is a shift from reading perceived as a precise process with its emphasis on bottom-up

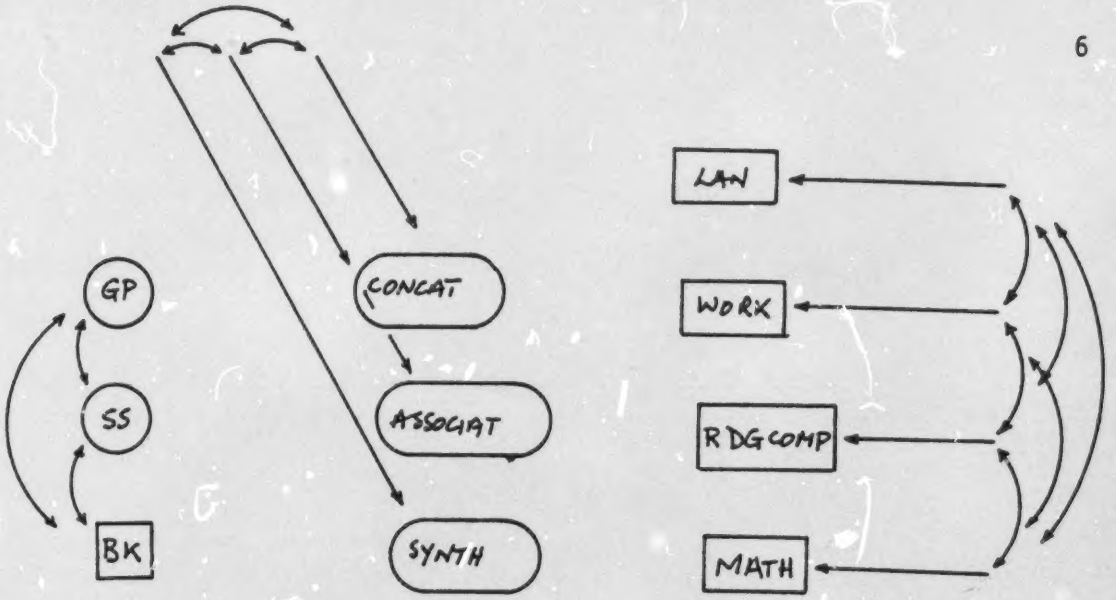


Chart 1A: Recursive Model of the Relationships between the Basic Skills and Information Processing Strategies[a]

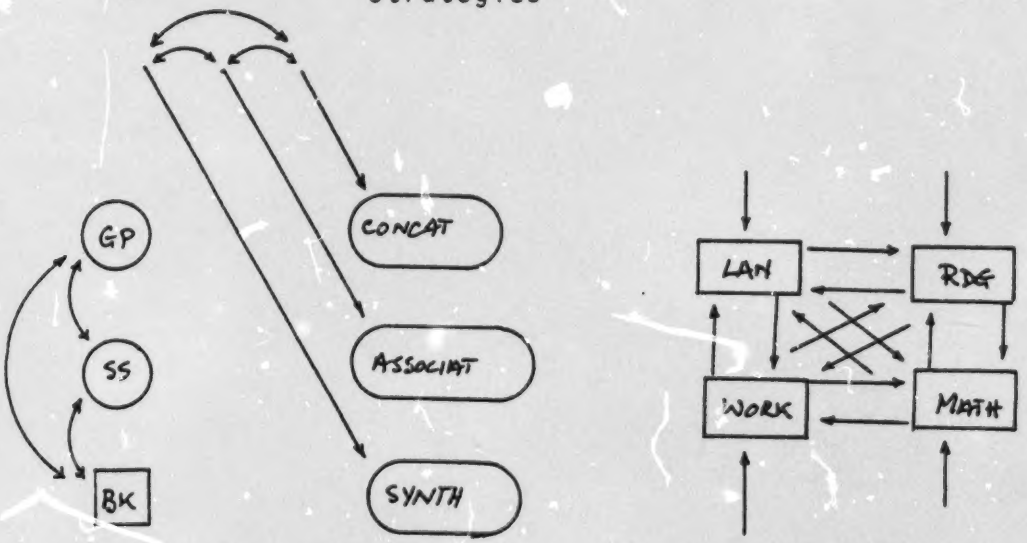


Chart 1B: Non-recursive Model of the Relationships between the Basic Skills and Information Processing Strategies[a]

[a]The inner relationships in Charts 3A and 3B have not been depicted in the interests of clarity. Variables on the right are hypothesized to be affected by every variable to the left.

Key to the mnemonics: GP = grapho-phonic strategy; SS = syntactic-semantic strategy; BK = background knowledge; CONCAT = concatenating discourse strategy; ASSOCIAT = associating discourse strategy; SYNTH = synthesizing discourse strategy; LAN = language skill; WORK = work study skill; RDG = reading comprehension; MATH = mathematics performance.

processing to reading perceived as a selective process with its emphasis on top-down processing. In the second place there is a shift from learning to read to reading to learn (cf. Gray 1956; and Chall 1979).

More explicitly, an early dependence on bottom-up processing as indicated by the grapho-phonic processing of text, is likely to give way to greater dependence on top-down processing by the time a child is reading at the grade four level. At the time grapho-phonic mastery becomes a constant for grade four readers the syntactic-semantic processing of text assumes greater variability. Similarly, in the later grades syntactic-semantic mastery becomes more of a constant and the synthesizing of information strategy assumes greater prominance. These notions give rise to two research questions: (i) Do these hypothesized shifts in information processing emphases actually occur in the case of reading? and (ii) If they do, can parallel shifts in emphasis be discerned for each of the additional basic skills -- language, workstudy and mathematics?

Are the Basic Skills Mutually Reinforcing?

We have already argued that achievement stimulates achievement in the elementary grades; that, therefore, the basic skills are mutually reinforcing; and that the non-recursive model depicted in Chart 1 is correctly specified.

We do not regard the multiple feedback specification of the basic skills as an issue. The problem here is that multiple feedback models, or models with greater than two feedback parameters, are extremely difficult to estimate using the conventional ordinary least squares (OLS) or maximum likelihood (ML) estimators. Both are extremely sensitive to multicollinearity.

Though we do not wish to burden the reader with mathematical detail, a brief discussion of the procedure adopted in this research for coping with the multicollineary problem seems advisable. At the outset the reader should know that using standard estimating techniques the parameter estimates would be difficult, if not impossible, to estimate.

The standard statistical solution to the multicollinearity problem is to use one of a family of biased, variance-reduced estimation methods collectively known as ridge regression (RR). In the presence of multicollinearity RR is usually more efficient than OLS in the sense that it usually generates smaller estimator variance (Vinod 1978). Since the commonest method of feedback estimation is a two-stage least squares (2SLS) procedure, in theory two-stage ridge regression (2SRR) should be able to outperform 2SLS. It has been argued elsewhere, however (Bulcock and Lee 1983; Bulcock et al. 1981), that RR is not a problem free method for reducing variance inflation and especially with the low signal to noise ratio ($\sum\beta_i^2/\sigma^2$) models which are usually

characteristic of school achievement research. RR is a stochastic procedure when it should be nonstochastic, and it does not meet the boundary condition. Thus, an alternative procedure which uses a variance normalization criterion was developed (Bulcock et al. 1981) that copes with the dilemmas of RR while still preserving the advantages of RR over OLS. Normalization ridge regression (NR) gives an unbiased OLS solution for orthogonal data and can be used to estimate nonorthogonal, recursive models. Two-stage normalization ridge regression (2SNR) may be used to estimate nonorthogonal, nonrecursive models (Lee et al. 1984). Because the non-recursive basic skills models are highly collinear the 2SNR estimator was used in this paper to obtain accurate feedback estimates. Quadruple feedback estimates were called for in the grade four model, while double feedback at two points in time was called for in the grade six longitudinal literacy-numeracy model.

Research Design and Models

Ninety-four grade four pupils (47 boys and 47 girls) -- all of whom were reading at the grade four level or higher -- were selected from four classrooms in two schools in order to test the theory developed in the previous section. All read the same 741 word passage which was about the length of the average story found in their grade four basal reader. Cueing strategy scores for each child were based on the procedures

described by Goodman and Burke (1973); while the child's discourse processing scores were based on the Kintsch (1974) model as modified by Drum and Lantaff (1977) and by Fagan (in Beebe et al. 1984). A vocabulary or word knowledge score corrected for guessing devised by Thorndike (1973) was used as a proxy for background knowledge. The basic skills variables were grade equivalent scores from the Canadian Tests of Basic Skills (CTBS) developed by King and Hieronymus (1974).

Basic information common to the models estimated in the findings section has been presented in Appendices. A description of the variables is given in Appendix A; and their correlations are presented in Appendix B. Note that there are three classes of variables: "I" variables are indicator variables used to construct the latent or composite variables in the models; "X" variables are the exogenous or source variables in the models; while "Y" variables are the endogenous variables.

The theory underlying this study of the interaction of the basic skills and reading is tested by estimating six models; namely,

(i) a revised model of discourse processing,

(ii) a recursive model of the responsiveness of children's basic skills in grade four to their information processing strategies,

(iii) a nonrecursive model of the responsiveness of children's basic skills in grade four to their information processing strategies,

(iv) a nonrecursive model of grade four literacy and numeracy,

(v) a longitudinal recursive model of grade six literacy and numeracy, and

(vi) a longitudinal nonrecursive model of grade six literacy and numeracy.

Conceptual diagrams of each model are presented in Appendix C along with the formal equations associated with each model.

Results

Model #1. The revised recursive model of discourse processing.

This model was revised on the basis of the results from Beebe's (1984) analysis of an integrated model of reading. First, Beebe showed that the concatenating and associating discourse strategies had negligible effects on reading comprehension; thus, they were dropped from further consideration. This left the synthesizing discourse strategy as the only dependent (Y) variable in Model #1. Second, the model was revised by including the vocabulary variable as a proxy for background knowledge. Though this was a compromise solution it seemed to work satisfactorily.

Comment. The F-ratio for the revised model was highly significant. See Table 1. The syntactic-semantic cueing strategy variable and the background knowledge variable were the important predictors of the synthesizing discourse strategy of grade four children.

Table 1 about here

Model #2. The responsiveness of the basic skills to the information processing strategies

The information processing strategies, in conjunction with a child's background knowledge, are extremely powerful predictors of reading comprehension. Note from Table 2 that there was a negative relationship between the grapho-phonic strategy and reading indicating that by grade four the over-dependence of the reader on bottom-up processing would inhibit his search for meaning. The most powerful predictor of grade four reading was the reader's use of top-down information processing. This, used in conjunction with the synthesizing strategy and background knowledge accounted for over fifty percent of the variance in reading comprehension.

As predicted by the theory the information processing strategies proved powerful predictors of the remaining basic skills -- language, work study and mathematics. Again, the impact of bottom-up processing was negative, but this time the effect was negligible. Note, too, the modest positive influence of the synthesizing strategy on language, work study and mathematics skills. What mattered the most were the effects of top-down processing in conjunction with background knowledge. Background knowledge had the most powerful impact on mathematics even though the instrument contained no background items in mathematics.

Table 1

Standardized Beta Coefficients and T-ratios for the Revised Model of Discourse Processing: OLS Analysis (N = 94)

Independent Variables	Dependent Variable Y_{19} SYNTH	
	Stand. B	t-ratio
X_5 GP	.067	0.678
X_6 SS	.282	2.743
X_{10} VOCAB	.214	2.046
F-ratio	5.820	
R-square	.163	
R-square adjusted	.135	

A feature of model #2 which should be mentioned concerns the covariation between the basic skills. As can be noted from the correlation matrix in Appendix B the intercorrelations between the basic skills ranged from .62 for reading and mathematics to .77 for reading and work study. The correlations between the residuals, however, ranged from .37 to .61 indicating that the information processing strategies and background knowledge were important common causes of the covariation. In other words, much of what the basic skills have in common may be attributed to the information processing abilities of children.

Table 2 about here

What we conclude from the analysis of Model #2 is that the use of top-down and synthesizing strategies along with background knowledge accounts for much of the variability in the basic skills. Clearly, information processing strategies underlie basic skills acquisition in grade four. Thus, the children with the most effective syntactic-semantic and synthesizing strategies and with the broadest background knowledge will be the most precocious in terms of their basic skills performances.

Table 2. Standardized Beta Coefficients and T-ratios for a Recursive Model of the Responsiveness of the Basic Skills to Information Processing Strategies[a]

Independent Variables	Dependent Variables							
	Y_{20} TLAN4		Y_{21} TWS4		Y_{22} RDG4		Y_{23} TMATH4	
	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio
X_5 GP	-.010	.105	-.056	.633	-.152	1.901	.001	.000
X_6 SS	.419	4.129	.323	3.383	.430	4.944	.394	4.015
X_{10} VOCAB	.201	1.986	.372	3.905	.274	3.160	.298	3.041
Y_{19} SYNTH	.121	1.208	.106	1.130	.193	2.280	.067	.691
F-ratio	10.228		13.573		21.348		11.559	
Mult. R	.584		.633		.723		.600	
R-square	.341		.401		.523		.361	
R-square adjusted	.308		.372		.498		.329	

a OLS Analysis.

Model #3. The interaction of basic skills and reading in grade four

The question, Does achievement stimulate achievement? is not new. But achievement models with more than two feedback parameters have seldom been estimated. The estimates of the interaction of basic skills and reading model reported in Table 3 support the theory but two findings were unanticipated.

The theory is supported in that the basic skills were found to be mutually reinforcing. But the thesis that the mutually reinforcing basic skills would also be responsive to children's information processing strategies was only conditionally supported. We return to the theory following a discussion of the two unanticipated findings.

In Model #2 the basic skills were found to be highly responsive to children's information processing strategies when they were taken one at a time. When the skills are examined in the context of a reciprocal outcomes model, however, as they are here, the information processing strategies were attenuated. Their direct effects were reduced. Their impact stemmed from the fact that they influenced the basic skills which, in turn, affected the outcome under observation. In other words the effects of the information processing strategies were predominantly indirect rather than direct.

A second unanticipated finding concerns the role of language skills. Language skill is an additive, unweighted,

combination of subtest scores in spelling, capitalization, punctuation and usage. The Table 3 results show that while performances on the other basic skills could be used to predict language skill, in the presence of the other factors language skills had little predictive value for the other basic skills. In conjunction with this finding one might note that work study skills were responsive to reading and mathematics; reading was most highly responsive to work study and mathematics; and mathematics was most responsive to work study and reading.

Table 3 about here

A reason for this state affairs suggests itself when one notes that the language skill subtests are composed largely of mechanical, lower-order or content items. Children were asked to identify the misspelled word in a list such as: (1) spend, (2) poor, (3) evry, (4) cost, (5) (No mistakes); or the mistake in capitalization as in the following example: (1) my brother has a turtle (2) for a pet, but i would, (3) rather have a hamster. (4) (No mistakes); or the mistake in punctuation as in the following question: (1) There was a date (2) carved on the tree. The (3) date was June 8 1941. (4) (No mistakes). The language usage questions failed to tap a child's syntactic mastery. The grade four subtest consisted of eleven items in which the pupil was asked to identify the mistakes in word usage. A typical item read as

Table 3. Standardized Beta Coefficients and T-ratios for the Interaction of Basic Skills and Reading in Grade Four[a]

Independent Variables	Dependent Variables							
	Y_{20} TLAN4		Y_{21} TWS4		Y_{22} RDG4		Y_{23} TMATH 4	
	Stand. B	t-ratio	Stand. B	t-ratio	Stand.B	t-ratio	Stand.B	t-ratio
X_5 GP	-.035	-.444	-.003	-.044	-.042	-.586	-.038	-.497
X_6 SS	.130	1.283	.041	.422	.097	1.092	.088	.923
X_{10} VOCAB	.041	.420	-.012	-.125	.120	1.369	.010	.104
Y_{19} SYNTH	.033	.383	.037	.438	.082	1.051	-.024	-.283
Y_{20} TLAN4	---	---	.176	1.765	.091	1.065	.009	.096
Y_{21} TWS4	.244	2.763	---	---	.141	2.206	.245	3.003
Y_{22} RDG4	.116	1.842	.135	2.218	---	---	.218	3.052
Y_{23} TMATH4	.003	.034	.194	2.119	.181	2.216	---	---
k	.140		.155		.154		.151	
R-square	.288		.291		.412		.304	
VIFmax	1.338		1.283		1.242		1.234	

a. 2SNR Analysis.

follows: (1) I come as soon as I could. (2) He can help himself. (3) What did you do with it? (4) (No mistakes).

In contrast, the reading subtest consisted of two passages followed by multiple choice comprehension questions about the passage. In order to obtain correct answers the child had to be able to make inferences, draw conclusions, and summarize information. In the work study subtests the pupil had to be able to read a map; interpret calendars, pie charts and tables; and demonstrate competence in sequencing information, interpreting a book index, and alphabetizing. In mathematics the subtests were in mathematics' concepts (which picture has a square inside a circle?) and mathematics' problem solving (Joe paid 35¢ for the sand and gravel for the aquarium. He gave the clerk a half dollar. How much change did Joe receive?).

The reading, work study and mathematics tests all involved reasoning skills to a greater degree than did the language test. Their content differed but their logical operations were similar and of a higher order than those required in the language test. Perhaps these logical similarities between the work study, reading and mathematics subtests accounted for the fact that they were reciprocally reinforcing; and why the language test had but modest predictive power in the nonrecursive model.

On the basis of this discussion two conclusions were drawn. In the first place, the important processes accounting for variability in the multiple feedback basic skills model

were the thinking, reasoning processes (Thorndike 1917); not the mechanical, content oriented processes. And, second, the results indicate that the cueing strategy model, the discourse processing model, and the basic skills model are complementary models -- at least at the grade four level.

Model #4. A nonrecursive model of grade four literacy and numeracy

Beginning with model #4 interest focuses on reading as a proxy for literacy and mathematics as a proxy for numeracy. It is the first of three models designed to examine the responsiveness of literacy and numeracy to children's information processing strategies over time.

The estimates of Model #4 reinforce Model #3 findings. Literacy and numeracy are mutually reinforcing. The effects of information processing strategies were largely indirect rather than direct. Thus, top-down processing and synthesizing in conjunction with background knowledge affected numeracy via literacy. Similarly, top-down processing and background knowledge affected literacy via numeracy. The conclusion, as before, was that the information processing theory of reading and the basic skills theory of reading are complementary theories.

Table 4 about here

Table 4

Standardized Beta Coefficients and T-ratios for the Nonrecursive Model of Literacy and Numeracy in Grade Four: 2SNR Analysis (N = 94)[a]

Independent Variables	Dependent Variables: Y_{19} SYNTH		Y_{22} RDG4		Y_{23} TMATH4	
	Stand.B	t-ratio	Stand.B	t-ratio	Stand.B	t-ratio
X_5 GP	.061	.658	-.059	-.846	-.054	-.712
X_6 SS	.272	2.810	.164	2.004	.154	1.758
X_{10} VOCAB	.207	2.114	.143	1.706	.112	.120
Y_{19} SYNTH			.118	1.561	-.001	-.009
Y_{22} RDG4			----	----	.366	4.169
Y_{23} TMATH4			.283	3.349	----	----
k-value (2nd stage)	.047		.159		.148	
R-square	.151		.391		.279	
VIFmax	1.039		1.135		1.195	

[a]Results of the first stage analysis [$y_{19} = b_1 x_5 + b_2 x_6 + b_3 x_{10} + u$] based on using a normalization ridge regression estimator.

Model #5. A longitudinal recursive model of grade six literacy and numeracy

Model #5 was designed primarily to examine the thesis that the impact of the information processing strategies that children use, shift as they get older. The intellectual resources of individuals are not constants. In his status attainment research Bulcock (1976) found that the quality of an individual's education tended to have but modest impact on income early in the socioeconomic career; and that the full effects were not manifest until mid-career -- in the early fifties. In the present study we have noted that by grade four the impact of the emphasis on bottom-up processing in the early grades has declined in favour of top-down processing. From Table 5 we note that the synthesizing discourse strategy increased in its impact on reading from grades four to six.

These findings may be spurious, however, because model #5 may be seriously misspecified. Students' information processing strategies in grade six were not available; hence, these important variables could not be included in the model. In particular there is a marked increase in background knowledge between grades four and six. To use grade four background knowledge as a predictor of grade six mathematics -- a school dependent as opposed to a home dependent factor -- was, in retrospect, naive.

Table 5 about here

Table 5

Standardized Beta Coefficients and F-ratios for the Longitudinal Recursive Model of Literacy and Numeracy in Grade Six: OLS Analysis (N = 94)

Independent Variables	Dependent Variables							
	Y_{22} RDG4		Y_{23} TMATH4		Y_{26} RDG6		Y_{27} TMATH6	
	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio
X_5 GP	-.150	-1.892	-.001	-.008	-.013	-.169	-.125	-1.521
X_6 SS	396	4.604	.384	4.000	.192	2.074	.272	2.723
X_{10} VOCAB	.259	3.023	.281	2.933	.251	2.909	.051	.549
Y_{19} SYNTH	.191	2.260	.063	.669	.256	3.124	-.011	-.125
Y_{22} RDG4					.182	1.697	.072	.618
Y_{23} TMATH4					.119	1.240	.389	3.746
F-ratio	19.370		11.143		16.860		12.365	
R-square	.465		.334		.538		.460	
R-square adjusted	.441		.304		.506		.423	

Grade six literacy and numeracy covaried. The correlation was .676, indicating that on the whole successful performance in one reinforced performance in the other. The grade four information processing strategies and grade four achievements in literacy and numeracy proved important common causes of this covariation since they accounted for forty-one percent of the covariation.

Model #6. A longitudinal nonrecursive model of grade six literacy and numeracy

Model #6 was a bold attempt to demonstrate the validity of two interdependent theories. Theory one holds that literacy and numeracy in grade six will be responsive to children's performances at an earlier point in time -- in this instance, their performances two grades earlier, in grade four. The performances of interest were in literacy and numeracy and in information processing. See the model relationships as specified in the diagram presented in Appendix C.6. Theory two holds that literacy and numeracy are mutually reinforcing outcomes of upper elementary schooling.

The model #6 findings in Table 6, however, do not provide clearcut support for the two theories. As expected, performances in literacy and numeracy in grade four proved powerful predictors of literacy and numeracy in grade six. Since literacy and numeracy in grade four mediated the effects of the information processing strategies, the indirect effects of these strategies (not calculated here) should not be underestimated.

So far, support for theory one is convincing. But support for theory two was not forthcoming. When taking into account literacy and numeracy in grade four the responsiveness of grade six reading to grade six mathematics was negligible; and the responsiveness of grade six mathematics to grade six reading was negative -- in the opposite direction to that hypothesized. These contradictory findings are puzzling.

How much confidence do we have in the finding that there is an absence of reciprocity between literacy and numeracy in grade six. Two speculative observations seem in order. By grade six students are eleven to twelve years old. They are beginning to develop their own expectations of what they want from school. They are beginning to respond to their school experiences in terms of the extent to which they support or frustrate their personal fulfillment expectations. Personal success in school is being defined not only in terms of cognitive development, but also in terms of whether the school is organized in such a way that the student's broader interests and expectations can be met. Student attitudes begin to play an increasingly important role in their development. Some pupils are defining some subjects differently than others -- especially the core subjects. Language and literature on the one hand and mathematics on the other.

Perhaps, then, the finding that literacy and numeracy outcomes in grade six are not reciprocal is not a spurious finding after all. Nevertheless, as noted in the discussion on Model #5, the model is still misspecified. The absence of grade six students' information processing data is a serious omission. Similarly, if personal fulfillment expectations are as important as suggested in the previous paragraph, perhaps attitude data should be obtained for incorporation in the model. Until a respecified model is estimated we shall not have answers to the question regarding the validity of what is described here as theory two. It is prudent, therefore to regard this perplexing question as one which remains for the time being unanswered.

Table 6 about here

Table 6

Standardized Beta Coefficients and F-ratios for the Longitudinal Nonrecursive Model of Literacy and Numeracy in Grade Six: 2SNR Analysis (N = 94)

Independent Variables	Dependent Variables: Y_{22} RDG4		Y_{23} TMATH4		Y_{26} RDG6		Y_{27} TMATH6	
	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio	Stand. B	t-ratio
X_5 GP	-.059	-.846	-.054	-.712				
X_6 SS	.164	2.004	.154	1.758				
X_{10} VOCAB	.143	1.706	.112	.120				
Y_{19} SYNTH	.118	1.561	-.001	-.009				
Y_{22} RDG4	----	----	.366	4.169	.324	4.218	.302	4.252
Y_{23} TMATH4	.283	3.349	----	----	.249	3.498	.399	5.007
Y_{26} RDG6					----	----	-.172	-1.893
Y_{27} TMATH6					.080	.967	----	
k-value (2nd stage)	.159		.148		.082		.090	
R-square	.391		.279		.423		.283	
VIFmax	1.135		1.195		1.152		1.254	

References

BEEBE, M.J. (1980). The effect of different types of substitution miscues on reading. Reading Research Quarterly, 15, 3, 324-336.

BEEBE, M.J. (1981). A model of the relationships between reading strategies and reading comprehension. Unpublished Doctoral Dissertation, University of Alberta, Edmonton, Alberta, Canada.

BEEBE, M.J. (1984). The integration of psycholinguistic and discourse processing theories of reading comprehension. Paper presented at the twenty-ninth Annual Convention, International Reading Association, Atlanta, Georgia.

BEEBE, M.J., BULCOCK, J.W., FAGAN, W.J. & MALICKY, G.V. (1984). Recall strategies and reading comprehension. Unpublished manuscript, Faculty of Education, Memorial University of Newfoundland, St. John's, Newfoundland, Canada.

BULCOCK, J.W. & BEEBE, M.J. (1981). Some common causes of literacy and numeracy. Canadian Journal of Education, 6, 3, 19-44.

BULCOCK, J.W., FAGERLIND, I. & EMMANUELSON, I. (1975). Education and the socioeconomic career in Sweden: An overview of recent research. Paper presented at the Meetings of the American Educational Research Association, Washington, D.C.

BULCOCK, J.W. & LEE, W.F. (1983). Normalization ridge regression in practice. Sociological Methods and Research, 11, 3, 259-303.

BULCOCK, J.W., LEE, W.F. & LUK, W.S. (1981). The theory of normalization ridge regression. ED 178 581. Washington, D.C.: National Institute of Education, Educational Resources Information Center.

CHALL, J.S. (1982). Stages of Reading Development. New York: McGraw-Hill.

DRUM, P.A. & LANTAFF, R.E. (1977). Scoring categories for protocols. Paper presented at The Second Annual Language Conference, Boston University.

GOODMAN, K.S. (1967). Reading: A psycholinguistic guessing game. Journal of the Reading Specialist, 6, 126-135.

GOODMAN, K.S. (1976). Behind the eye: What happens in reading. In H. Singer & R. Ruddell (Eds.), Theoretical Models and Processes in Reading. Newark, Del.: International Reading Association.

GOODMAN, Y.M. & BURKE, C.L. (1973). Reading miscue inventory. New York: McMillan.

GOUGH, P.B. (1972). One second of reading. In J. Kavanagh & I. Mattingly (Eds.), Language by Ear and by Eye. Cambridge, Mass.: MIT Press.

GOUGH, P.B. & COSKY, M.J. (1977). One second of reading again. In N.J. Castellan, Jr., D.B. Pisoni & G.R. Potts (Eds.), Cognitive Theory, Hillsdale, N.J.: Lawrence Erlbaum Associates.

GRAY, W. (1956). The teaching of reading and writing: An international survey. New York: Unesco.

KING, E.M. & HIERONYMUS, A.N. (1974). Canadian tests of basic skills. Toronto: Thomas Nelson.

KINTSCH, W. (1974). The representation of meaning in memory. Hillsdale, N.J.: Lawrence Erlbaum Associates.

KINTSCH, W. (1976). Memory for prose. In C.N. Cofer (Ed.), The structure of human memory. San Francisco: Freeman.

KINTSCH, W. & VAN DIJK, T.A. (1978). Toward a model of text comprehension and production. Psychological Review, 85, 363-394.

KINTSCH, W. & VIPOND, D. (1979). Reading comprehension and readability in educational practice and psychological theory. In L. Nilsson (Ed.), Proceedings of the conference on memory. University of Uppsala. Hillsdale, N.J.: Lawrence Erlbaum Associates.

LEE, W.F., BULCOCK, J.W. & LUK, W.S. (1984). The R-square ridge trace in 2SLS regression estimation. Sociological Methods and Research (forthcoming).

LESGOLD, A.M. & PERFETTI, C. (1981). Interactive processes in reading. Hillsdale, N.J.: Lawrence Erlbaum Associates.

MEYER, B.J.F. (1975). The organization of prose and its effect on recall. Amsterdam: North Holland.

MEYER, B.J.F. (1977). What is remembered from prose: A function of passage structure. In R.O. Freedle (Ed.), Discourse production and comprehension (Vol. 1). Norwood, N.J.: Ablex.

RUMELHART, D.E. (1977). Toward an interactive model of reading. In S. Dornic (Ed.), Attention and performance V1. Hillsdale, N.J.: Lawrence Erlbaum Associates.

SMITH, F. (1971). Understanding reading. New York: Holt, Rinehart & Winston.

SMITH, F. (1973). Decoding: The great fallacy. In F. Smith (Ed.), Psycholinguistics and reading. Toronto: Holt, Rinehart & Winston.

SMITH, F. (1978). Reading and nonsense. New York: Teachers College Press.

THORNDIKE, E.L. (1917). Reading as reasoning: A study of mistakes in paragraph reading. Journal of Educational Psychology, 8, 323-332.

THORNDIKE, R.L. (1973). Reading comprehension education in fifteen countries: International Studies in Education III. Stockholm: Almqvist & Wiksell.

VAN DIJK, T.A. (1977). Macro-structures and cognition. In M. Just & P. Carpenter (Eds.), Cognitive processes in comprehension. Hillsdale, N.J.: Lawrence Erlbaum Associates.

VINOD, H.D. (1978). A survey of ridge regression and related techniques. Review of Economics and Statistics, 60, 121-131.

APPENDIX A

A DESCRIPTION OF THE VARIABLES

Description of the Variables

Type of Variable[a]	Variable Number	Variable Name	Variable Description	$\bar{X}$	SD	Values Min	Values Max
I	1	PGRSIM	Proportion miscues graphically similar	66.17	10.22	42.31	90.38
I	2	PPHSIM	Proportion miscues phonetically similar	63.66	10.81	34.62	90.38
I	3	PSYNAC	Proportion miscues syntactically acceptable	58.83	12.16	25.98	93.48
I	4	PSEMAC	Proportion miscues semantically acceptable	63.64	17.11	16.54	97.83
X	5	GP	Grapho-phonic cueing strategy	.00	.98	-2.06	5.75
X	6	SS	Syntactic-semantic cueing strategy	.00	.93	-2.70	2.35
X	7	SCHOOL	School attended	1.48	.50	1.00	2.00
X	8	AGE	Age of pupil in months	113.00	5.10	96.00	113.00
X	9	SEX	Sex	1.5	.50	1.00	2.00
X	10	VOCAB	Vocabulary score	34.62	9.27	1.00	51.00
I	11	TSPEC	Text specific recall	4.56	4.76	.00	22.00
I	12	TENT	Text entailed recall	8.71	5.63	1.00	24.00
I	13	TERR	Text erroneous recall	2.91	2.49	.00	12.00
I	14	DESCR	Descriptive information processing	-.01	.99	-1.9	4.3
I	15	ASSOC	Associative information processing	.02	.95	-2.08	3.40
I	16	INTEG	Integrative information processing	.00	1.00	-1.56	3.76
Y	17	CONCAT	Concatenating discourse strategy	.01	1.00	-2.02	4.29
Y	18	ASSOCIAT	Associating discourse strategy	.01	1.00	-2.37	2.95
Y	19	SYNTH	Synthesizing discourse strategy	.00	1.00	-2.02	3.47
Y	20	TLAN4	CTBS Total language score, grade 4	47.14	8.62	27.00	68.00
Y	21	TWS4	CTBS Total work study score, grade 4	45.08	7.76	26.00	68.00
Y	22	RDG4	CTBS Reading comprehension, grade 4	45.46	8.76	27.00	67.00
Y	23	TMATH4	CTBS Total math score, grade 4	44.19	6.56	30.00	62.00
Y	24	TLAN6	CTBS Total language score, grade 6	71.97	9.41	39.00	94.00
Y	25	TWS6	CTBS Total work study score, grade 6	71.71	9.83	48.00	93.00
Y	26	RDG6	CTBS Reading comprehension, grade 6	70.36	9.88	35.00	91.00
Y	27	TMATH6	CTBS Total math score, grade 6	70.34	9.46	40.00	92.00

[a] I = indicator variable; X = exogenous or predetermined variables; Y = endogenous variables.

APPENDIX B

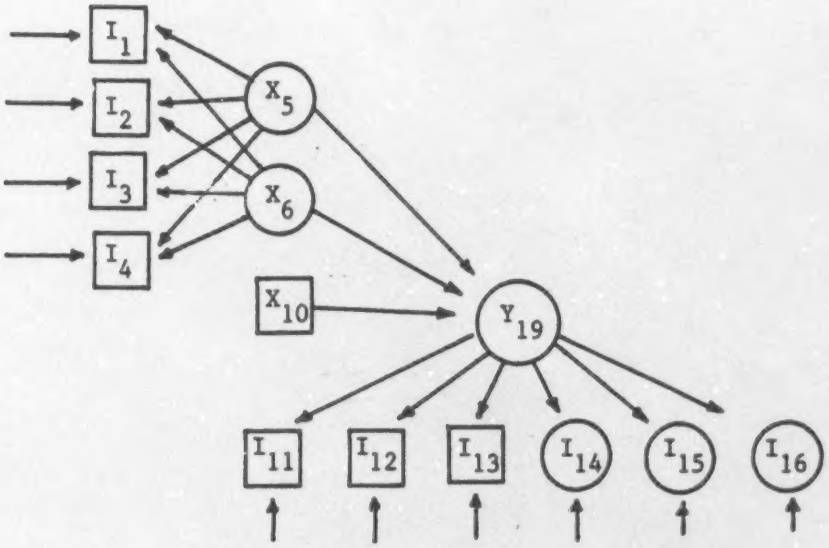
MATRIX OF CORRELATIONS

Correlations, Means and Standard Deviations for Variables in the Basic Skills and Literacy-Numeracy Models (N = 94)

Variables No.	Mnemonic	1	2	3	4	5	6	10	11	12	13	14	15	16	19	20	21	22	23	24	25	26	27
1	PGRSIM																						
2	PPHSIM	.889																					
3	PSYNAC	-.093	-.103																				
4	PSEMAC	-.090	-.104	.752																			
5	GP	.809	.793	-.136	-.114																		
6	SS	-.071	-.082	.935	.935	-.101																	
10	VOCAB	-.030	-.086	.319	.342	-.196	.348																
11	TSPEC	-.161	-.170	.228	.254	-.067	.256	.162															
12	TENT	-.068	-.094	.277	.329	.037	.326	.241	.714														
13	TERR	.098	.051	.016	-.184	.126	-.086	-.276	.305	.269													
14	DESCR	-.156	-.150	.115	.082	-.076	.103	-.015	.650	.575	.449												
15	ASSOC	.083	.016	.117	.085	.084	.110	.077	.325	.424	.356	-.022											
16	INTEG	-.081	-.062	.196	.271	.051	.252	.169	.425	.477	-.076	-.003	-.117										
19	SYNTH	-.134	-.122	.265	.387	-.004	.350	.299	.669	.729	-.143	.212	.076	.900									
20	TLAN4	-.165	-.132	.406	.530	-.089	.498	.367	.186	.226	-.168	-.065	.143	.234	.315								
21	TWS4	-.180	-.134	.415	.483	-.159	.477	.504	.139	.284	-.137	-.031	.157	.244	.318	.648							
22	RDG4	-.212	-.172	.516	.558	-.242	.569	.484	.236	.338	-.225	.029	.147	.287	.408	.628	.747						
23	TMATH4	-.209	-.167	.463	.482	-.095	.504	.434	.184	.337	-.089	.077	.222	.163	.282	.617	.702	.603					
24	TLAN6	-.083	-.109	.507	.554	-.070	.566	.276	.155	.277	-.037	.021	.150	.181	.254	.646	.503	.508	.491				
25	TWS6	-.217	-.180	.548	.634	-.208	.627	.396	.212	.345	-.139	.142	.058	.219	.336	.546	.577	.541	.512	.662			
26	RDG6	-.143	-.206	.473	.532	-.138	.534	.537	.357	.480	-.122	.122	.191	.365	.506	.536	.549	.593	.508	.668	.740		
27	TMATH6	-.247	-.175	.481	.530	-.217	.536	.371	.114	.274	-.169	.039	.125	.123	.239	.479	.569	.512	.601	.607	.792	.676	
	$\bar{X}$	68.2	63.6	58.8	63.6	.001	.003	34.6	4.56	8.71	2.91	.011	.022	.001	.002	47.1	45.1	45.5	44.2	71.9	71.7	70.4	70.3
	SD	10.2	10.8	12.1	17.1	.984	.929	9.27	4.76	5.63	2.49	.994	.951	.998	.999	8.62	7.76	8.76	6.56	9.41	9.83	9.88	9.46

APPENDIX C

CONCEPTUAL DIAGRAMS AND EQUATIONS FOR MODELS 1 THRU 6



Key: I's refer to indicator variables; X's refer to exogenous variables; Y refers to the dependent variable. Variables enclosed in boxes are observed variables; variables enclosed by a circle are latent variables. I_1 = proportion of miscues graphically similar, I_2 = proportion of miscues phonetically similar, I_3 = proportion of miscues syntactically acceptable, I_4 = proportion of miscues semantically acceptable, X_5 = grapho-phonic cueing strategy, X_6 = syntactic-semantic cueing strategy, X_{10} = vocabulary test score, I_{11} = text specific information processing strategy, I_{12} = text entailed information processing strategy, I_{13} = text erroneous information processing strategy, I_{14} = descriptive information processing, I_{15} = associative information processing, I_{16} = integrative information processing, Y_{19} = synthesizing discourse processing strategy.

Figure 1

The Revised Model of Discourse Processing

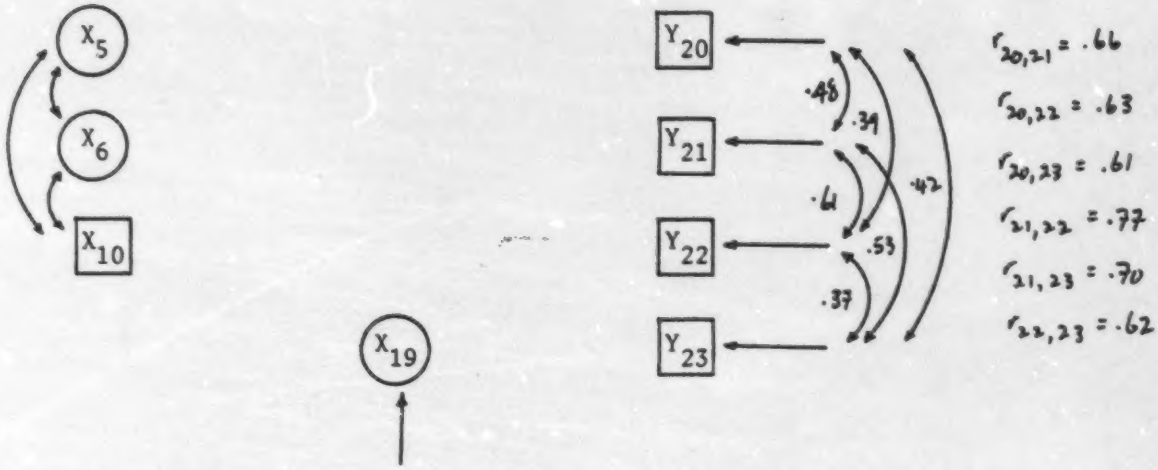
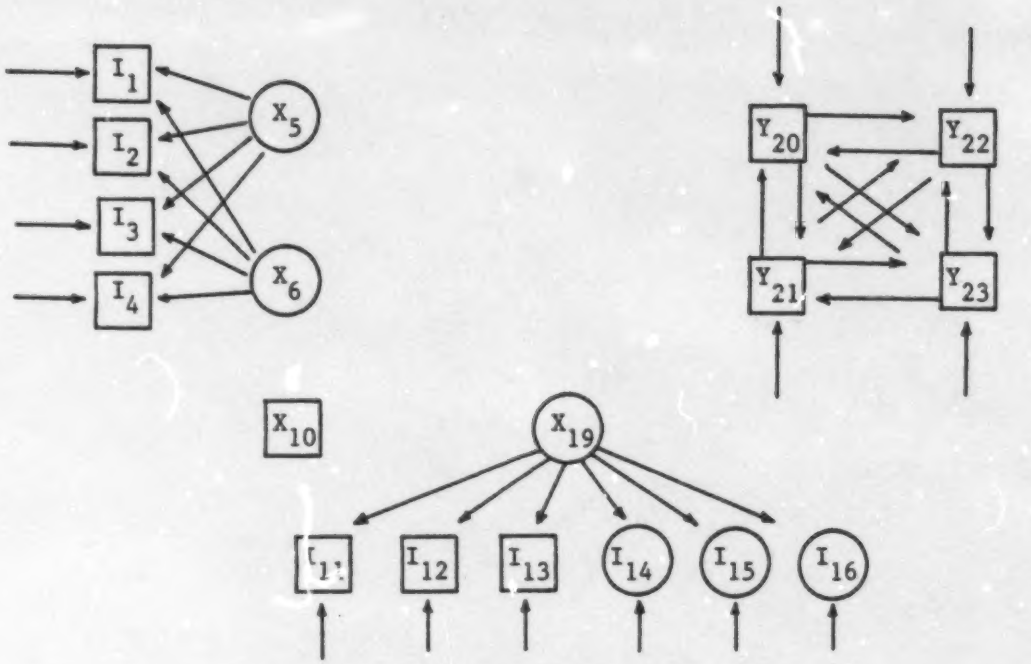


Figure 2. A Recursive Model of the Responsiveness of Children's Basic Skills in Grade Four to their Information Processing Strategies



Key: I's refer to indicator variables; X's to exogenous variables: Y's to endogenous variables. Variables in boxes are observed variables; variables in circles are latent variables. I_1 = proportion of miscues graphically similar, I_2 = proportion of miscues phonetically similar, I_3 = proportion of miscues syntactically acceptable, I_4 = proportion of miscues semantically acceptable, X_5 = grapho-phonic cueing strategy, X_6 = suntactic-semantic cueing strategy, X_{10} = vocabulary test score, I_{11} = text specific recalls, I_{12} = text entailed recalls, I_{13} = text erroneous recalls, I_{14} = descriptive information processing, I_{15} = associative information processing, I_{16} = integrative information processing, Y_{19} = synthesizing discourse strategy, Y_{20} = total language score, Y_{21} = total work study skill score, Y_{22} = reading comprehension score, Y_{23} = total mathematics score.

Figure 3

Conceptual Model of the Responsiveness of Basic Skills Performances in Grade Four to Information Processing Strategies

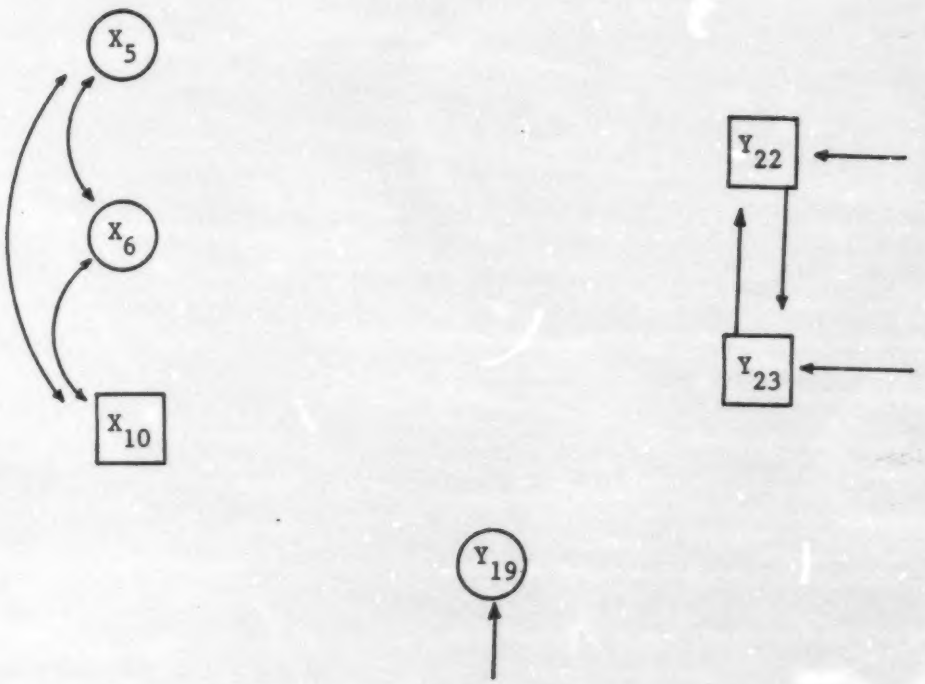
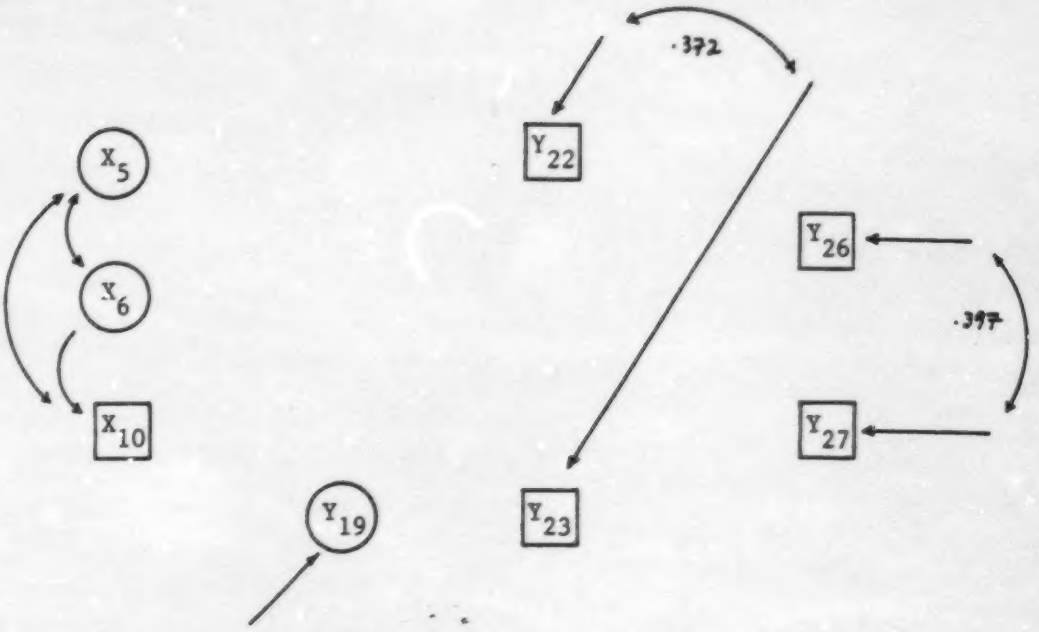


Figure 4

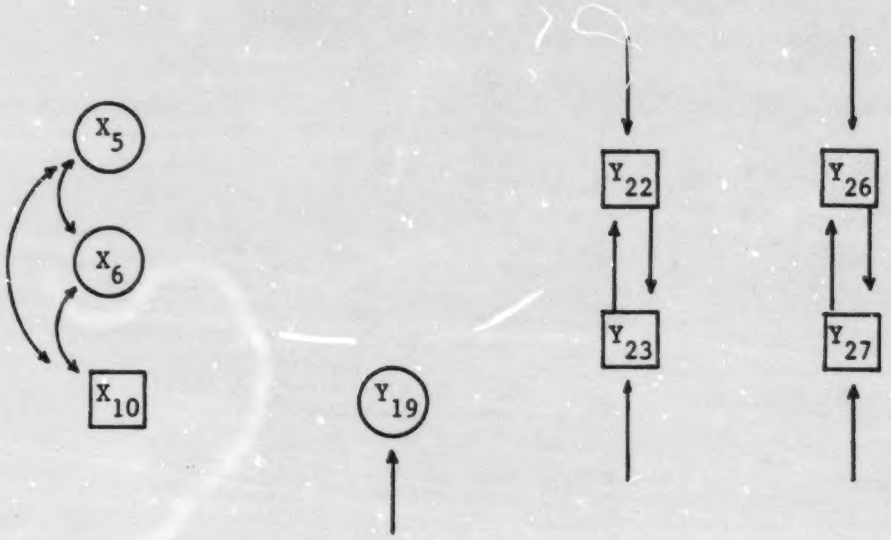
Nonrecursive Model of Literacy and Numeracy in Grade Four



Key: X_5 = grapho-phonic cueing strategy, X_6 = syntactic-semantic cueing strategy, X_{10} = vocabulary test score, Y_{19} = synthesizing discourse strategy, Y_{22} = reading comprehension in grade four (proxy for grade four literacy), Y_{23} = total mathematics score in grade four (proxy for grade four numeracy), Y_{26} = reading comprehension in grade six, Y_{27} = total mathematics score in grade six.

Figure 5

Longitudinal Recursive Model of Literacy and Numeracy in Grade Six



Key: X_5 = grapho-phonic cueing strategy in grade four, X_6 = syntactic-semantic cueing strategy in grade four, X_{10} = vocabulary test score in grade four, Y_{19} = synthesizing discourse strategy in grade four, Y_{22} = reading comprehension in grade four, Y_{23} = total mathematics score in grade four, Y_{26} = reading comprehension in grade six, Y_{27} = total mathematics score in grade six.

Figure 6

Longitudinal Nonrecursive Model of Literacy and Numeracy in Grade Six

Model Equations

Model #1: OLS Estimates

Identities:

$$X_5 \equiv w_1 I_1 + w_2 I_2 + w_3 I_3 + w_4 I_4 \quad (1\text{-}1)$$

$$X_6 \equiv w_1 I_1 + w_2 I_2 + w_3 I_3 + w_4 I_4 \quad (1\text{-}2)$$

$$Y_{19} \equiv w_1 I_{11} + w_2 I_{12} + w_3 I_{13} + w_4 I_{14} + w_5 I_{15} + w_6 I_{16} \quad (1\text{-}3)$$

where I, X and Y variables are defined as in Appendix A and standardized, and where $w_1 \ldots w_n$ are weights (in these models the weights are factor score coefficients).

Equations

$$Y_{19} = b_1 x_5 + b_2 x_6 + b_3 x_{10} + u_1 \quad (1\text{-}4\text{-}1)$$

$$y_{19} = .067 \times x_5 + .282 \times x_6 + .214 \times x_{10} + .915 \quad (1\text{-}4\text{-}2)$$
$$(t=0.678) \quad (t=2.743) \quad (t=2.046)$$

Model #2: OLS Estimation

eq. (1-4-1)

$$Y_{20} = b_1 x_5 + b_2 x_6 + b_3 x_{10} + b_4 y_{19} + u_2 \quad ((2\text{-}5\text{-}1)$$

$$Y_{20} = (-010) \times x_5 + .419 \times x_6 + .201 \times x_{10} +$$
$$(t=0.105) \quad (t=4.129) \quad (t=1.986)$$

$$.121 \times y_{19} + .812 \quad (2\text{-}5\text{-}2)$$
$$(t=1.208)$$

$$Y_{21} = b_1 x_5 + b_2 x_6 + b_3 x_{10} + b_4 y_{19} + u_2 \quad (2\text{-}6\text{-}1)$$

$$Y_{21} = (-.056) \times x_5 + .323 \times x_6 + .372 \times x_{10} +$$
$$(t=0.633) \quad (t=3.383) \quad (t=3.905)$$

$$.106 \times y_{19} + .774 \quad (2\text{-}6\text{-}2)$$
$$(t=1.130)$$

$$Y_{22} = b_1 x_5 + b_2 x_6 + b_3 x_{10} + b_4 y_{19} + u_3 \quad (2\text{-}7\text{-}1)$$

$$Y_{22} = (-.152) \times x_5 + .430 \times x_6 + .274 \times x_{10} +$$
$$(t=1.901) \quad (t=4.944) \quad (t=3.160)$$

$$.193 \times y_{19} = .691 \quad (2\text{-}8\text{-}1)$$
$$(t=2.260)$$

$$Y_{23} = b_1x_5 + b_2x_6 + b_3x_{10} + b_4y_{19} + u_4 \quad (2\text{-}8\text{-}1)$$

$$Y_{23} = \underset{(t=0.000)}{.001 \times x_5} + \underset{(t=4.015)}{.394 \times x_6} + \underset{(t=3.041)}{.298 \times x_{10}} +$$

$$\underset{(t=0.691)}{.067 \times y_{19}} + .799 \quad (2\text{-}8\text{-}2)$$

Model #3: 2SNR Estimation

The nonrecursive 2SNR equations are of the general form:

$$y_m = X_m b + Y_m c + u \quad (3\text{-}9)$$

where X_m is the matrix of the included exogenous variables; Y_m is the matrix of included endogenous variables; y_m is the dependent variable in the mth structural equation in the model; b and c are vectors of structural equation coefficients associated with X_m and Y_m respectively; and u is the vector of residuals in the equation.

Note that equation (3-1) is not solved stage by stage (assuming it is identifiable); rather, it is computed by using its explicit form (Johnston, 1972: 396):

$$d = \left[Z_m'X(X'X)^{-1}X' \; Z_m\right]^{-1} Z_m'X(X'X)^{-1}X'y_m \quad (3\text{-}10)$$

where $d = \binom{b}{c}$ is the column vector of estimated coefficients b and c; $Z_m = [X_m, y_m]$ is the matrix of all explanatory variables, both endogenous and exogenous in the equation, and X is the matrix of all exogenous variables in the model.

$$Y_{20} = c_1y_5 + c_2y_6 + c_3y_{10} + c_4y_{19} + c_5y_{21} + c_6y_{22} +$$

$$c_7y_{23} + (b_1x_1 + \ldots + b_4x_4 + b_5x_{10} + \ldots + b_{11}x_{16})$$

$$+ u \quad (3\text{-}11\text{-}1)$$

$$Y_{20} = (-.035) \times y_5 + .130 \times y_6 + .041 \times y_{10} + .033 \times y_{19} +$$
$$(t=-.444) \qquad (t=1.283) \qquad (t=.420) \qquad (t=.383)$$
$$.244 \times y_{21} + .116 \times y_{22} + .003 \times y_{23} + .844 \qquad (3\text{-}11\text{-}2)$$
$$(t=2.763) \qquad (t=1.842) \qquad (t=.034)$$

$$Y_{21} = c_1y_5 + c_2y_6 + c_3y_{10} + c_4y_{19} + c_5y_{20} + c_6y_{22} +$$
$$c_7 y_{23} + (b_1x_1 + \ldots + b_4x_4 + b_5x_{10} + \ldots + b_{11}x_{16})$$
$$+ u_2 \qquad (3\text{-}12\text{-}1)$$

$$Y_{21} = (-.003) \times y_5 + .041 \times y_6 + (-.012) \times y_{10} + .037 \times y_{19} +$$
$$(t=-.044) \qquad (t=.422) \qquad (t=-.125) \qquad (t=.438)$$
$$.176 \times y_{20} + .135 \times y_{22} + .194 \times y_{23} + .842 \qquad (3\text{-}12\text{-}2)$$
$$(t=1.765) \qquad (t=2.218) \qquad (t=2.119)$$

$$Y_{22} = c_1y_5 + c_2y_6 + c_3y_{19} + c_4y_{10} + c_5y_{19} + c_6y_{21} + c_7y_{23} +$$
$$(b_1x_1 + \ldots + b_4x_4 + b_5x_{10} + \ldots + b_{11}x_{16}) + u_3 \qquad (3\text{-}13\text{-}1)$$

$$Y_{22} = (-.042) \times y_5 + .097 \times y_6 + .120 \times y_{10} + .082 \times y_{19} +$$
$$(t=-.586) \qquad (t=1.092) \qquad (t=1.359) \qquad (t=1.051)$$
$$.091 \times y_{20} + .141 \times y_{21} + .181 \times y_{23} + .767 \qquad (3\text{-}13\text{-}2)$$
$$(t=1.065) \qquad (t=2.206) \qquad (t=2.216)$$

$$Y_{23} = c_1y_5 + c_2y_6 + c_3y_{10} + c_4y_{19} + c_5y_{20} + c_6y_{21} + c_7y_{22} +$$
$$(b_1x_1 + \ldots + b_4x_4 + b_5x_{10} + \ldots + b_{11}x_{16}) + u_4 \qquad (3\text{-}14\text{-}1)$$

$$Y_{23} = (-.038) \times y_5 + .088 \times y_6 + .010 \times y_{10} + (-.024) \times y_{19} +$$
$$(t=-.497) \qquad (t=.923) \qquad (t=.104) \qquad (t=-.283)$$
$$.009 \times y_{20} + .245 \times y_{21} + .218 \times y_{22} + .834 \qquad (3\text{-}14\text{-}2)$$
$$(t=.096) \qquad (t=3.003) \qquad (t=3.052)$$

Model #4: 2SNR Estimation

Eq. (1-4-1)

$$Y_{22} = c_1y_5 + c_2y_6 + c_3y_{10} + c_4y_{19} + c_5y_{23} + (b_1x_1 + \ldots +$$
$$b_4x_4 + b_5x_{11} + \ldots + b_{10}x_{16}) + u \qquad (4\text{-}15\text{-}1)$$

$$Y_{22} = -.059 \times y_5 + .164 \times y_6 + .143 \times y_{10} +$$
$$(t=-.846) \quad (t=2.004) \quad (t=1.706)$$

$$.118 \times y_{19} + .283 \times y_{23} + .780 \qquad (4\text{-}15\text{-}2)$$
$$(t=1.561) \quad (t=3.349)$$

$$Y_{23} = c_1y_5 + c_2y_6 + c_3y_{10} + c_4y_{19} + c_5y_{22} + (b_1x_1 + \ldots +$$

$$b_4x_4 + b_5x_{11} + \ldots + b_{10}x_{16}) + u \qquad (4\text{-}16\text{-}1)$$

$$Y_{23} = -.054 \times y_5 + .154 \times y_6 + .112 \times y_{10} + (-.001) \times y_{19}$$
$$(t=-.712) \quad (t=1.758) \quad (t=.120) \quad (t=-.009)$$

$$+ .366 \times y_{22} + .849 \qquad (4\text{-}16\text{-}2)$$
$$(t=4.169)$$

Model #5: OLS Estimation

Eq. (1-4-1)

$$Y_{22} = b_1x_5 + b_2x_6 + b_3x_{10} + b_4y_{19} + u_1 \qquad (5\text{-}17\text{-}1)$$

$$Y_{22} = (-.150) \times x_5 + .396 \times x_6 + .259 \times x_{10} + .191 \times y_{19}$$
$$(t=-1.892) \quad (t=4.604) \quad (t=3.023) \quad (t=2.260)$$

$$+ .731 \qquad (5\text{-}17\text{-}2)$$

$$Y_{23} = b_1x_5 + b_2x_6 + b_3x_{10} + b_4y_{19} + u_2 \qquad (5\text{-}18\text{-}1)$$

$$Y_{23} = (-.001) \times x_5 + .384 \times x_6 + .281 \times x_{10} + .063 \times y_{19}$$
$$(t=-.008) \quad (t=4.000) \quad (t=2.933) \quad (t=.669)$$

$$+ .816 \qquad (5\text{-}18\text{-}2)$$

$$Y_{26} = b_1x_5 + b_2x_6 + b_3x_{10} + b_4y_{19} + b_5y_{22} + b_6y_{23} + u_3 \qquad (5\text{-}19\text{-}1)$$

$$Y_{26} = (-.013) \times x_5 + .192 \times x_6 + .251 \times x_{10} + .256 \times y_{19} +$$
$$(t=-.169) \quad (t=2.074) \quad (t=2.309) \quad (t=3.124)$$

$$.182 \times y_{22} + .119 \times y_{23} + .680 \qquad (5\text{-}19\text{-}2)$$
$$(t=1.697) \quad (t=1.240)$$

$$Y_{27} = b_1x_5 + b_2x_6 + b_3x_{10} + b_4y_{19} + b_5y_{22} + b_6y_{23} + u_4 \qquad (5\text{-}20\text{-}1)$$

$$Y_{27} = (-.125) \times x_5 + .272 \times x_6 + .051 \times x_{10} + (-.011) \times y_{19} +$$
$$(t=-1.521) \qquad (t=2.723) \qquad (t=.549) \qquad (t=-.125)$$
$$.072 \times y_{22} + .389 \times y_{23} + .735 \qquad (5\text{-}20\text{-}2)$$
$$(t=.618) \qquad (t=3.746)$$

Model #6: 2SNR Estimation

Eq.(1-4-1)

Eq. (4-15-1)

Eq. (4-16-1)

$$Y_{26} = c_5y_{22} + c_6y_{23} + c_8y_{27} + (b_1x_1 + \ldots + b_4x_4 +$$
$$b_5x_{11} + \ldots + b_{10}x_{16}) + u_1 \qquad (6\text{-}21\text{-}1)$$

$$Y_{26} = .324 \times y_{22} + .249 \times y_{23} + .080 \times y_{27} + .760 \qquad (6\text{-}21\text{-}1)$$
$$(t=4.218) \qquad (t=3.498) \qquad (t=.967)$$

$$Y_{27} = c_5y_{22} + c_6y_{23} + c_7y_{26} + (b_1x_1 + \ldots + b_4x_4 +$$
$$b_5x_{11} + \ldots + b_{10}x_{16}) + u_2 \qquad (6\text{-}22\text{-}1)$$

$$Y_{27} = .302 \times y_{22} + .399 \times y_{23} + (-.172) \times y_{26} + .847 \qquad (6\text{-}22\text{-}2)$$
$$(t=4.252) \qquad (t=5.007) \qquad (t=-1.893)$$